Powering the Near Future 10G Access Network

Considerations for Assuring Sufficient and Reliable Power

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

The 10G initiative is the catalyst behind several technology innovations designed to deliver future proof internet speeds up to 100 times faster than most consumers are experiencing today. These innovations will affect every aspect of the broadband network including headends, the access network and the customer premises. The access network specifically must undergo enhancements to support performance levels envisioned by the 10G initiative. Many of these network revisions involve technology that is either new or under development. Operators will need to make decisions about implementing new technology to be certain that their networks will be able to handle whatever is coming. A service provider's existing network architecture along with the cost for upgrades will steer operators towards the technologies right for their needs. Network upgrade options may include anything from standard node splits and remote PHY (R-PHY) node upgrades to potentially disruptive technologies like 5G fixed wireless or fiber overlays. Regardless of the network upgrade specifics, power is a common requirement for any network.

Assuring the availability of additional, reliable and intelligent power for the 10G capable network is both essential and challenging since network architectures are evolving and much of the 10G enabling technology is still being developed. In this paper we address the access network powering challenge by providing operators with a set of powering guidelines. Our objective is to help ensure that sufficient, reliable network power is available, irrespective of the specific technologies implemented to meet network performance objectives. We accomplish this by first describing a 10G reference access network. Our reference network includes architectures and technologies that are both current and that are under development. Next, we overlay our reference network with the appropriate powering architecture. Existing hybrid fiber coax (HFC) powering infrastructure is re-used wherever practical. Some new 10G network elements may require new and innovative powering options. While no single service provider would incorporate every element of our 10G reference network, operators can plan powering strategies to support those network upgrades that will meet their future performance goals.

2. The Near Future 10G Network

In early 2019 the 10G initiative was announced with the objective of providing 10Gbps symmetrical, secure, low latency data services. CableLabs coined the phrase near future in connection with 10G. A CableLabs paper provides the following description of the 10G near future network: "Immersive experiences like interactive holographic projections, video walls and next-generation artificial intelligence (AI) and virtual reality (VR) tools will all require a super high-capacity network that can deliver an immense amount of data to the end user ... 10G technologies will enable speeds 10 times faster than the 1 gigabit speeds that cable offers today, equally applied to both the upstream and downstream traffic over existing cable hybrid fiber coax (HFC) networks [1]."

Our 10G reference access network includes existing technologies and technologies that are under development. Figure 1 – 10G Influenced Technologies, highlights some 10G influenced technologies and their relative location in the broadband network.

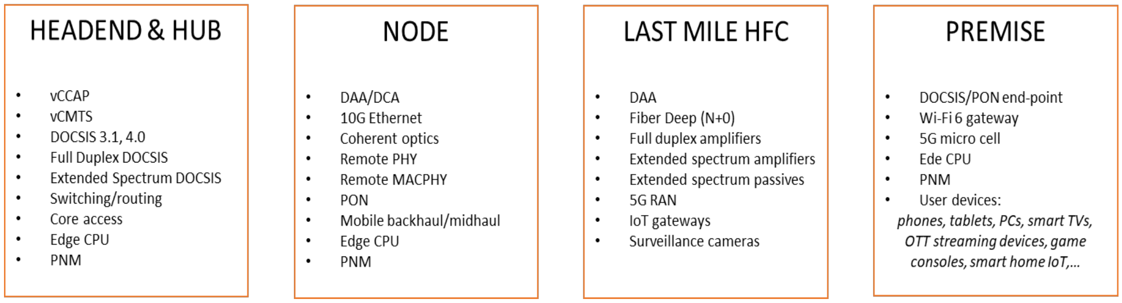

Figure 1 – 10G Influenced Technologies

Our discussion will focus on elements contained in the node and last mile HFC blocks shown in Figure 1. These access network elements are within the scope of our powering discussion.

2.1. Distributed Access Architecture (DAA) and Distributed CCAP Architecture (DCA)

Distributed Access Architecture (DAA) relocates or distributes functions that traditionally reside in the headend or hub closer to the user. Moving functions deeper into the network reduces power and space demands in the headend/hub. As functions move closer to users the network experiences increase in efficiencies, speed, reliability, latency and security [2]. Distributed CCAP Architecture (DCA) outlines specific technologies to distribute headend functions to the distributed network [3]. For the intent of our powering discussion DAA and DCA will be considered the same and we shall use the term DAA going forward.

2.2. Remote PHY and Flexible MAC Architecture

Remote PHY (R-PHY) and Flexible MAC Architecture (FMA) are implementations under the DAA umbrella. Both technologies move processing functions from the headend/hub to distributed optical nodes as shown in this diagram.

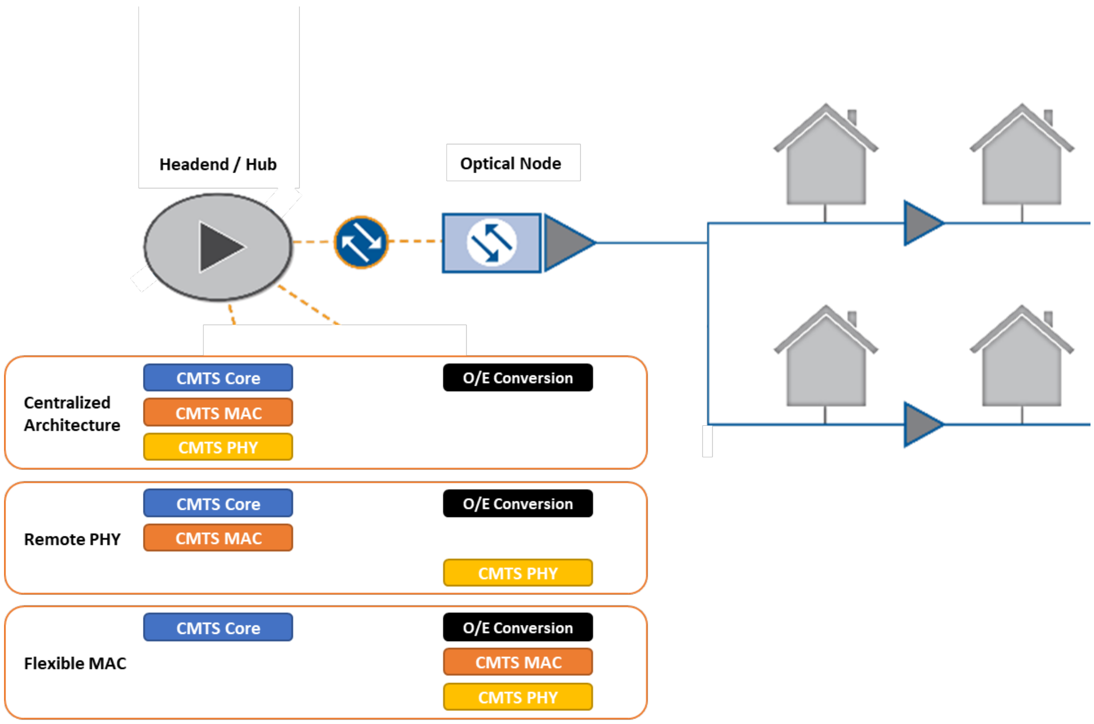

Figure 2 – DAA Configurations

Operators transitioning from traditional analog nodes to DAA nodes must increase their node power budget. Analog nodes consuming about 80W each are replaced by DAA nodes requiring more power (assuming similar configurations). Current industry data indicates that DAA node power consumption is in the range of 140W to 190W with FMA capable nodes requiring more power than R-PHY capable nodes. As field programmable gate arrays (FPGA) and application specific integrated circuits (ASIC) evolve, this power consumption is expected to improve. For our DAA node power budget we'll assume a nominal value of 165W per node.

At the time of this paper's publication DOCSIS™ 4.0 has not yet been implemented in DAA nodes. DOCSIS 4.0 radio frequency (RF) signaling, including Full Duplex DOCSIS (FDD) and Extended Spectrum DOCSIS (ESD) with downstream spectrum support to 1,794 MHz, are generated in the PHY component of the DAA node [4]. Specific power requirements for DOCSIS 4.0 enabled DAA nodes are not known. For estimating purposes we'll assume that future DOCSIS 4.0 enabled DAA node power requirements fit within our estimated DAA power budget of 165W.

Beyond the current DOCSIS 4.0 standards, there are industry proposals to extend the downstream spectrum beyond 1.8GHz to 3GHz. This next-generation RF band upgrade could enable upstream speeds in excess of 9 Gbps and downstream speeds to 25 Gbps. The proposal utilizes small RF amplifiers near the premises, providing signal amplification for the 1.2GHz to 3GHz range [5]. The impact of this enhanced RF spectrum on the HFC power network would be speculative at this stage so we will leave powering this concept for a future discussion.

2.3. Coherent Optics Backhaul

Coherent optics, or full duplex point to point (P2P) coherent optics, uses amplitude and phase to carry large amounts of bidirectional data over a single fiber using a single wavelength. In the DAA cable environment, coherent optics will be used to establish high-capacity links from the headend/hub to an aggregation node or directly to the DAA node. The current state of the industry supports 100Gbps outdoor rated coherent optics pluggable modules with 200Gbps and 400Gbps modules planned for the future. Our access network powering model will consider two potential coherent optics use cases. First is a coherent optics module providing high speed backhaul direct to the DAA. Today's coherent optics modules consume approximately 15W which will be added to our DAA node power budget. Next, we consider the addition of an optical distribution center (ODC) or virtual hub containing the coherent optical components as well as Ethernet switching elements. An access network with an ODC is pictured here [6].

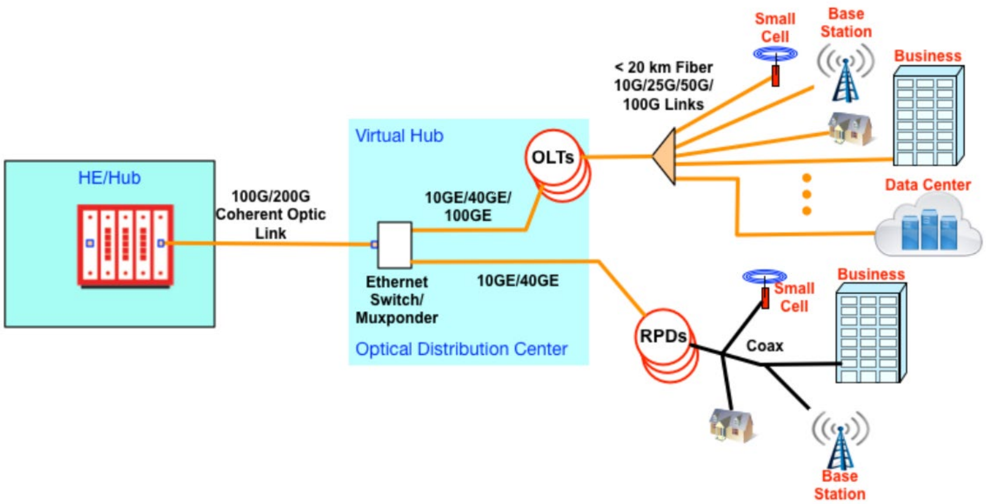

Figure 3 – ODC/Virtual Hub Architecture

In this network the ODC is shown supporting optical outputs to DAA nodes (RPDs) as well as supporting OLT functions for passive optical network (PON) network segments. For power budgeting purposes the ODC will be considered a strand mount style element with power consumption of 150W. Powering the ODC or other virtual hubs can be more challenging than powering optical nodes. With the ODC, there are no coax connections to source power to any of the fiberoptic inputs and outputs. If the ODC is installed in a location formerly occupied by an optical node then powered coax may be available at the location to power the ODC. If powered coax is not available, alternative powering options can include anything from installing a dedicated power cable from nearby powered coax to installing a new uninterruptable power supply (UPS) at the ODC location. Irrespective of the power input source, the operator will consider the ODC a critical location requiring extremely reliable power due to the number of downstream subscribers serviced by this device.

2.4. Generic Access Platform (GAP) Nodes

The SCTE Interface Practices Subcommittee, Working Group 1 (IPS WG1) is defining a set of specifications for a Generic Access Platform (GAP) node housing. One objective of the GAP node is "increased availability and ability to integrate advanced technologies within a modular approach [7]." Integrating additional technologies inside the node housing will increase power consumption which is why the GAP is mentioned here. Future plug-in modules discussed during GAP committee sessions include: radio access network (RAN) (Wi-Fi, 5G and citizen broadband radio service (CBRS)), Ethernet passive optical network (EPON) and edge computing modules. These three potential node enhancements are discussed here.

2.4.1. RAN Module

A potential access network upgrade includes a RAN component, potentially taking the form of 5G fixed wireless radio units (RU's) utilizing the coax for power and backhaul. It is not likely the DAA node physical location will align with RU location requirements for signal coverage. For simplicity we assume the DAA does not incorporate wireless modules. A 5G fixed wireless access network extension is discussed in section 3.4.2.

2.4.2. EPON Module

EPON modules could be installed in a DAA (GAP or traditional) node enclosure. A challenge comes with attempting to define a standard configuration. Some EPON components are light weight, layer 2 devices that combine with cloud based processing for full featured performance. One module from a well-known component vendor supports 2x10GigE x 2x10GEPON and consumes only 35W. Specifications for more full featured EPON units supporting 4x10GigE x 4x10GEPON and including native processing support for features such as DOCSIS provisioning over Ethernet (DPoE) and layer 3 networking have been identified as consuming up to 140W. To avoid numerous permutations of EPON and RF QAM node configurations and to simplify our powering discussion it is assumed that our DAA node may support one basic EPON module at 35W.

2.4.3. Edge Compute Module

CableLabs in 2020 announced a program called Adrenaline intended to "transform the network into a distributed heterogeneous compute platform with dynamic workload allocation". The Adrenaline concept is shown here [8].

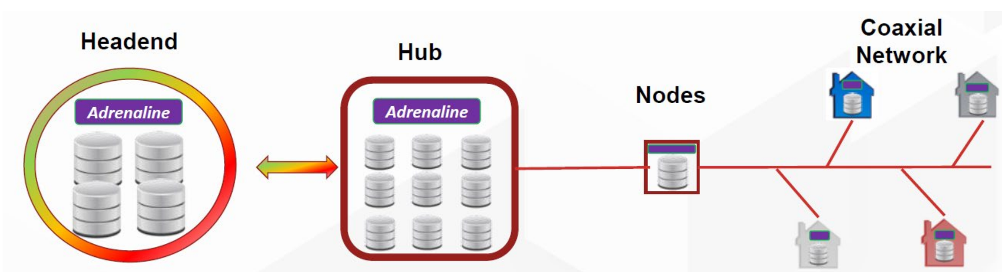

Figure 4 – Edge Compute Concept from CableLabs

An Adrenaline type distributed, or edge computing concept has been the topic of multiple industry webinars. Edge computing is distributed to intelligent components throughout the network, including the DAA node. The cable broadband industry is a few years away from realizing speed and performance improvements from distributed edge computing, but many are working towards this goal. For our access network powering budget, we assume our near future DAA node will be fitted with a processing module. Power estimates at this stage are speculative but let's assume our DAA processing element will add an additional 10W power requirement to the node.

2.5. DAA Node Power Budget Summary

From our near future access network concept node review the following table summarizes our DAA node powering budget.

Table 1 – DAA Node Power Budget

Configuration	Power (W)
DAA (RPHY/ FMA) node	165
Coherent optical node backhaul	15
Edge compute module	10
Total DAA node power budget	190
Adding EPON	35
DAA with RF and EPON	225

Our DAA node of the future requires significantly more power than traditional analog nodes. This difference combined with other related access network upgrades give cause to review powering assumptions and consider evolving needs.

3. Powering The 10G Access Network

3.1. Traditional HFC Power Review

The access network includes all network elements beyond the headend/hub and up to the premises. Some network architectures utilize virtual hubs housed within outdoor sealed enclosures which are also considered part of the access network. A simplified access network block diagram is shown in Figure 5.

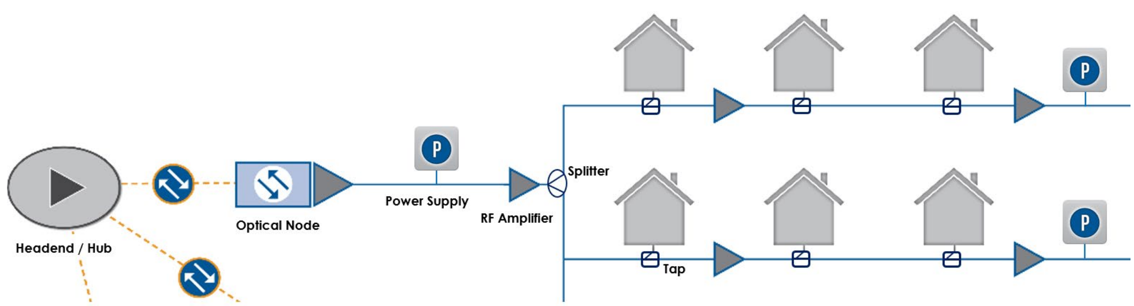

Figure 5 – Traditional HFC Access Network

In the traditional HFC access network signals from the headend/hub are transmitted over fiber optic cable to optical nodes. Nodes convert between optical and electrical signals and convey those signals to multiple coax network segments. Each coax segment typically consists of a tree-and-branch structure for signal distribution. Passive splitters subdivide the signal into multiple paths (branches). Amplifiers are located throughout the coax network segment to boost signals, providing appropriate signal levels to the end users, which are typically homes and businesses. Directional taps located near the end users will "tap off" the signal from the main coax cable into drop cables which bring the signals into the customer premises. Nodes and amplifiers require power. Power is also consumed by coax line loss from Joule heating (I^2R losses). Power and RF signals are both multiplexed onto the coax, eliminating the need for separate power and signal cables. Power supplies are placed as needed throughout the access network to provide power to nodes and amplifiers.

3.1.1. HFC Power Supplies

Power for HFC components is provided by a specialized backup power system known as a broadband UPS. UPS systems are physically located throughout the coax portion of the network where required to provide power for each active network element. UPSs are physically installed on outdoor utility poles, in dedicated ground mounted enclosures, and in secured utility areas of multi-dwelling units (MDUs). A typical utility pole mounted broadband UPS is shown in Figure 6.

Figure 6 – Typical Pole Mounted Broadband UPS

The UPS converts utility power (120VAC or 240VAC in North America) to 90VAC for insertion into the coax. Early cable networks used 30VAC then later 60VAC for network power. Today, networks almost exclusively use 90VAC power with a few older 60VAC networks still in operation.

Unlike utility service which provides sinusoidal AC power, the broadband UPS produces a quasi-square wave or trapezoidal shaped power output. This wave shape is a result of the ferro-resonant transformer used in broadband UPS systems. The ferro-resonant transformer provides a high level of electrical isolation, protecting powered nodes and amplifiers from utility line power surges and transients that could damage sensitive electronics.

Batteries within the UPS system enable the power supply to provide continuous, reliable backup power to the access network during utility disruptions. The output of the UPS is connected to a power inserter, which acts like a reverse directional tap, to inject power onto the coax cable. Some operators use the term "shunt" to describe the process of injecting power or shunting power onto the coax.

Each amplifier, splitter and tap can be configured to pass power through itself and on to the next device in the network or to block power from passing through itself. The decision to pass or block power within a specific network device is determined by the operator and is based on criteria including:

- Do downstream devices require power and if so, how much?
- Does the UPS have sufficient capacity to power future planned devices?
- Will powering additional devices cause this UPS to exceed the cable broadband operator's maximum powering policy?

3.1.2. HFC Powering Example

Figure 7 uses a simplified HFC network segment to illustrate some basic powering concepts. In practice, HFC powering is more complex than illustrated but several basic principles are shown.

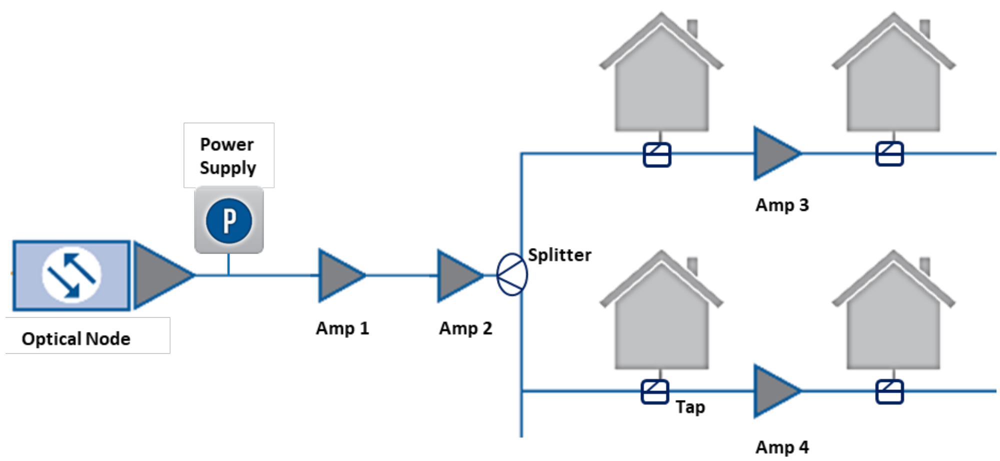

Figure 7 – HFC Powering Example

As stated, the diagram represents a simplified HFC network segment. In this example a broadband UPS is connected near the optical node. The node is powered from this coax segment. Amplifiers 1-4 are also powered from this UPS. Amplifier 1 and amplifier 2 are each configured to pass power through their chassis, enabling downstream devices to be powered from the UPS. The splitter is configured to pass power through both outputs. Amplifiers 3 and 4 are powered from the UPS and are configured to block power from passing to their respective outputs eliminating additional power draw from any components further down the coax.

Assume that the node requires 80W of power and amplifiers 1-4 each require 70W of power to operate. Also assume the UPS output is configured to 90VAC and that it has the capacity to provide up to 1350W of power. For simplicity, ignore coax line loss. The total power required is calculated as the sum of power required from each network active:

$$P(\text{Actives}) = P(\text{node}) + P(\text{amp1}) + P(\text{amp2}) + P(\text{amp3}) + P(\text{amp4})$$

$$\text{Total Power (Actives)} = 80W + (70W \times 4) = 360W$$

To make our example more realistic we include coax line loss in our power equation. Assume all coax is 0.625 inches diameter which has a typical resistance of 0.0011 ohms/feet. Also, assume the following coax span lengths.

Table 2 – Coax Spans for HFC Powering Example

From	To	Span (ft)
UPS	node	~0
node	amp 1	1,000
amp 1	amp 2	1,000
amp 2	splitter	1,000
splitter	amp 3	1,000
splitter	amp 4	1,000

Note: Using these assumptions, the total coax length between the UPS and amplifier 3 or the UPS and amplifier 4 is 4000ft.

Let's calculate the power lost in a single 1,000ft segment of coax. Using Ohm's Law:

$$P(loss) = I^2R$$

Where:

P(loss) = power lost from coax line resistance, measured in Watts. Note: this energy is converted to heat, hence the term Joule heating for I^2R losses.

I = current through the cable, measured in amps

R = resistance of the length of cable, measured in Ohms

Taking amplifier 1 in isolation, we calculate the power lost in the coax segment between the UPS and amplifier 1 as follows:

$$P(loss) = (70W/90V)^2 \times (0.0011 \text{ ohm/ft} \times 1{,}000\text{ft}) = 0.67 \text{ W}$$

In this example we used the Ohm's law relationship: I = P/V for the first term.

I=P/V is an ideal approximation. In real-world calculations we must account for accumulative voltage drops across each coax segment, i.e., the 90VAC at the UPS output is reduced through each coax segment. The voltage drop is proportional to both cable resistance and current per the relationship:

$$V(drop) = I(cable) \times R(cable)$$

HFC active elements, including nodes and amplifiers, are typically constant power devices. As input voltage to a device is reduced due to coax line resistance, the device's current will increase to maintain the required power load (P=VI). As the current increases, power loss through the coax increases. Recall this relationship discussed earlier: P(loss) = I^2R.

In this example the node and four amplifiers require 360W to operate. Additional energy consumed (lost) due to voltage drops across the various coax segments can be calculated to be an additional 36W. Detailed calculations have been omitted for brevity. Results are summarized as in Table 3.

Table 3 – HFC Powering Example Results

Configuration	PS I(out)	EOL Voltage	Actives Load	I^2R Loss	PS Utilization
Analog node, 4x Amplifiers	4.4A	79.4V	360W	35.5W	29%

With the UPS capacity of 1350W we've consumed 29% of the available power. End of line (EOL) voltage is another important parameter to monitor. EOL voltage is the input voltage of the last active device in the network and must remain above 45V for most HFC equipment to operate. For this example, we're well within acceptable operating parameters for UPS power and EOL voltage. This approach to HFC powering has worked well for many years. However, as the access network is upgraded to support our future 10G performance goals we will soon see how our powering approach must also be revised.

3.2. Powering the Evolving Access Network

Traditional HFC powering assumptions and methods must be reviewed as the underlying technology and in some cases the topology of the access network evolves to support higher performance and additional services. Section 3.2 examines a few of those network upgrades and their effect on the underlying power.

3.2.1. Node Splits

Node splits are familiar to most operators as a method of increasing upstream capacity by reducing a node service group size. If one node services 400 homes, then two nodes can service 200 homes each. Benefits come from reducing upstream (US) traffic contention. US DOCSIS utilizes time division multiple access techniques to enable many users to share the same US frequencies. Each user is granted specific time slots for US transmissions. Smaller service groups through node splits mean fewer users contending for shared upstream capacity.

Powering new nodes after a node split is usually straightforward. Existing broadband UPS systems are often already installed within existing node segments. New nodes often get installed closer to the premises and may result in eliminating amplifiers which can offset incremental power required for the new nodes.

Node splits have limitations. US bandwidth is capped by the US diplex frequency defined in each network. A low split 5-42MHz US diplexer can support about 100Mb/s of data while a 5-85Mhz mid-split diplexer can handle roughly 200Mb/s of US data. Multi-gigabit US performance requires a different approach.

3.2.2. Deep Fiber (N+0)

Expanding the node split concept to the point where all network amplifiers have been replaced by optical nodes leads to a deep fiber architecture consisting of a node + zero amplifier (N+0) configuration. Using DAA nodes in this configuration results in powerful, high performing nodes closer to the end user than ever before. With N+0 there are only passive components and coax between the DAA node and the premises. Potential data speeds are substantially higher than those possible from the traditional HFC network. Using technologies such as full duplex DOCSIS (FDD), extended spectrum DOCSIS (ESD) or both together can bring network performance much closer to the vision of the 10G concept.

However, powering an N+0 network may not be a straightforward transition from our traditional HFC powered network. Let's review a simple example to illustrate some potential challenges.

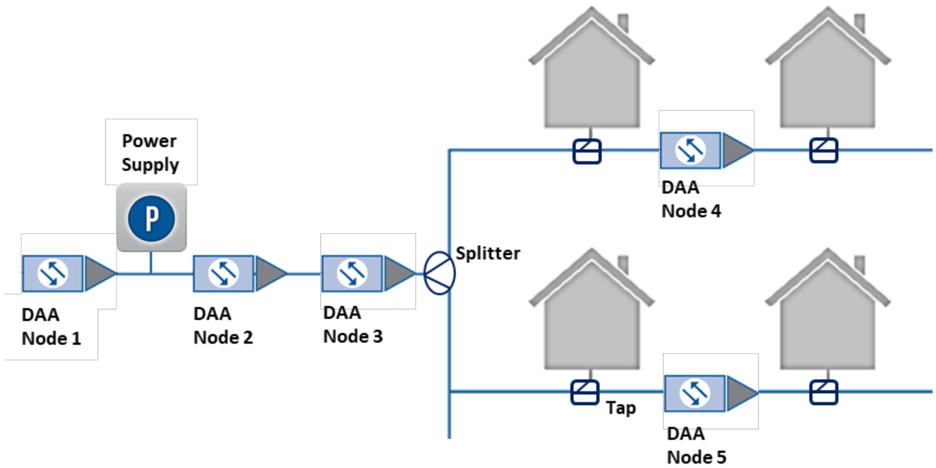

Figure 8 – DAA N+0 Powering Example

For our N+0 powering example we use the future DAA node defined in Table 1. Also, we're reusing the HFC node + amplifier layout from our HFC powering example but replacing the amplifiers with DAA nodes. Figure 8 shows the coax path to each DAA node. The coax is used for power only. Separate fiber connections not shown in this example carry the high speed data signals to each node.

Assume the UPS capacity is 1,350W and is configured for 90V output. Also assume that the EOL voltage must remain >45V for the nodes to operate. With our future DAA node requiring 190W, power for the active network elements is calculated as follows:

P(Actives) = P(node1) + P(node 2) + P(node 3) + P(node 4) + P(node 5)

Total Power (Actives) = 190W x 5 = 950W

To include coax line loss in our power equation, assume all coax is 0.625in diameter with resistance of 0.0011 ohm/ft. Assume the following coax span length:

Table 4 – Coax Spans for DAA N+0 Powering Example

From	To	Span (ft)
UPS	Node 1	~0
Node 1	Node 2	1,000
Node 2	Node 3	1,000
Node 3	Splitter	1,000
Splitter	Node 4	1,000
Splitter	Node 5	1,000

Note: Using these assumptions, the total coax length between the UPS and Node 4 or Node 5 is 4,000ft.

In this example the total power needed for the DAA nodes is 950W. However, higher current flow through the coax results in 560W of I^2R power loss. Total power for this scenario is 1,510W which exceeds our UPS' capacity making this configuration invalid. Results are summarized here:

Table 5 – DAA N+0 Powering Example Results

Configuration	PS I(out)	EOL Voltage	Actives Load	I^2R Loss	PS Utilization
DAA node x 5, N+0	17A	50.1V	950W	560W	133%

In this example the 1,350W UPS would be overloaded to 133% of capacity. It's also noteworthy that the EOL voltage has dropped to 50.1V. This is still above the 45V minimum but should be monitored as alternative powering is considered.

One option to solve our N+0 power overload is to install a second UPS and distribute the load between multiple power supplies. Adding UPS systems to the network is usually the operators last resort. Unplanned equipment costs and installation delays due to permits and local regulations can be problematic. Rather than default to installing new UPS systems as our corrective action let's look at another approach. By removing one of the DAA nodes from our test example we can solve part of our problem. Let's remove node 5 from our example, leaving the UPS to power nodes 1-4. Results follow:

Table 6 – Modified DAA N+0 Powering Example Results

Configuration	PS I(out)	EOL Voltage	Actives Load	I^2R Loss	PS Utilization
DAA node x 4, N+0	10.5A	68.5V	760W	171W	70%

By removing one node our powering model now works and results in our UPS loaded to 70% capacity. Many operators place design limits on UPS utilization of between 80-85% of the UPS' capacity to reserve overhead for unplanned changes.

So how do we power the stranded node from our example? Keep in mind that this example was created specifically to illustrate the effects of I^2R losses. In a live network many variables could affect the results. A few possible outcomes include:

- As the N+0 node architecture was implemented there would likely be multiple amplifiers decommissioned as part of the network upgrade. It's probable that the UPS would have spare capacity to power new nodes.
- Surplus UPS power from an adjacent coax segment could be routed to the new node(s).
- The UPS could be upgraded to a higher capacity to support the load and the required overhead (spare) power reserves.

Some operators have incorporated powering design rules into their network upgrade procedures to address these types of powering concerns. One major North American operator has established these options to address powering issues during advanced node upgrades:

- All power designs will assume advanced nodes will use existing power supplies. If any powering issues arise, the following will be allowed in order of preference:
    - Repowering of the nodes from adjacent node/power supply areas
    - 0.875" coax or dedicated power cable may be placed to reduce I^2R losses
    - 15-Amp power supplies may be changed to 18-Amp at existing locations fed by 120VAC
    - 15 or 18-Amp power supplies may be added to the network
    - 15-Amp power supplies may be changed to 24-Amp at existing locations fed by 240VAC
- To prevent an overcurrent of line passives or active devices, all 24-Amp power supplies must include a protective interface module (PIM) to split current output and provide two

programmable, independent power outputs providing isolation between outputs so that a short circuit or other power anomaly in one section of the HFC plant will not cause a disruption of service to all plant fed from that power supply.

If our sample unpowered node were in an actual network, it's probable that a nearby coax segment would have enough power capacity to handle one additional node. Power from an adjacent coax segment can be bridged to the unpowered node using a technique similar to Figure 9:

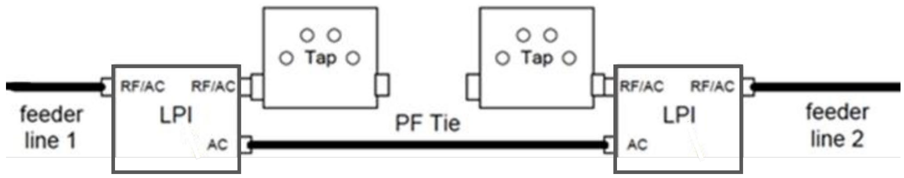

Figure 9 – Coax Power Bridging

This power bridging technique was developed by a major North American cable operator to solve the type of power shortage problem outlined in our example. Using this method power is bridged from one distribution leg to another while RF signals are blocked. RF signals from the node connected to feeder line 1 will support customers downline from the left tap while RF signals from the node connected to feeder line 2 support customers downline from the right side tap.

3.2.3. 1.8 GHz Extended Spectrum

A widely discussed approach for increasing access network capacity is extending the upper limit of the usable RF spectrum to 1,794 MHz (1.8GHz). This approach is well defined in the DOCSIS 4.0 specifications [4]. What is not yet well understood at the time of this writing is the access network topology that will support the 1.8GHz extended spectrum. The DOCSIS specifications allow for different transmission profiles for frequencies above 1,002 MHz. Amplifiers capable of supporting the extended spectrum may be configured in such a way as to support higher frequencies at limited power levels. Once extended spectrum equipment is available, operators can evaluate network specific implementations to achieve their objectives. Then, the effect of extended spectrum implementations on power can be determined.

3.2.4. 5G Fixed Wireless Access

The final communications link connecting end user devices such as phones, tablets and laptops is wireless. Wi-Fi 6 boasts peak data speeds in excess of 9 Gbps. Some operators are planning to deploy in-home 5G femtocells. 5G peak data rates can exceed 10 Gbps. A 5G small cell serving multiple homes on a street or throughout a neighborhood could realize similar data rates. This approach is called fixed wireless access (FWA). FWA is the process of providing wireless broadband using an RF link between two fixed points: a home and a small cell for example.

5G FWA could be either disruptive or complementary to cable providers. A telco or overbuilder with fiber capacity in a specific geographic area could use that fiber for backhaul and overlay a broadband radio area network (RAN) on top of the cable operator's service area to compete for broadband customers. This is clearly disruptive. Conversely, the cable operator could utilize 5G FWA to extend service to areas with no service or poor service without the expense of upgrading each premises and the surrounding infrastructure.

Powering an FWA network segment is similar to powering other HFC active network elements. Power per device, coax length between devices and distance from the power supply all factory into the powering equation. A simple example shown in Figure 10 illustrates the concept.

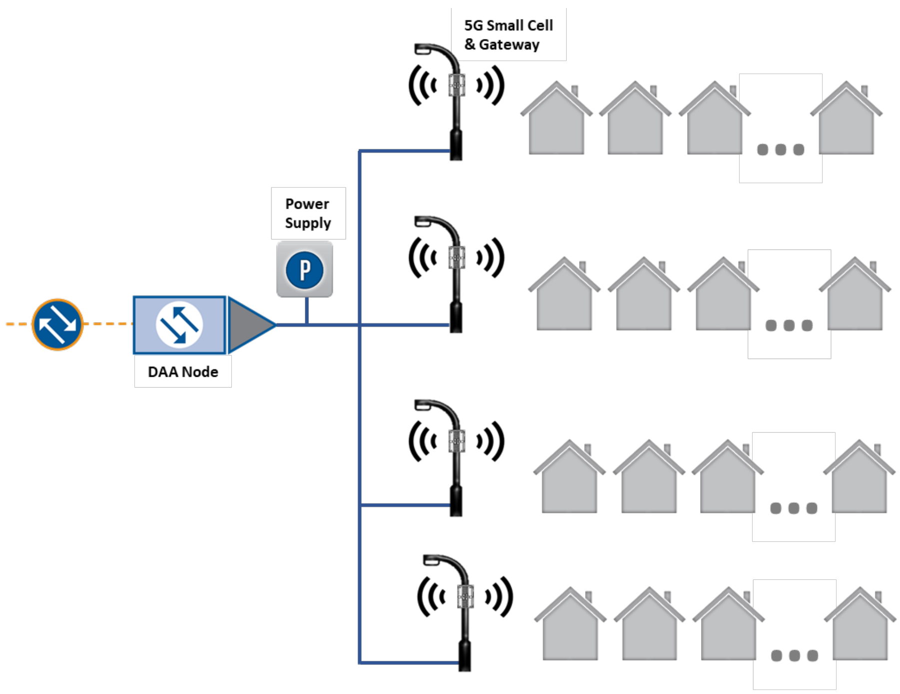

Figure 10 – 5G Fixed Wireless Access Powering

In this example a DAA node is shown servicing a neighborhood. Assume 4 small cell radios can service a total of 100 homes. To keep this example simple let's, make the following assumptions:

- The node and UPS power supply are co-located near a 4-way splitter
- Coax length from the splitter to each small cell is 1,500ft
- The UPS is configured to 90VAC output and is rated at 1350W
- The DAA optical node consumes 190W
- Each small cell requires 100W to power
- A gateway device interfaces each small cell radio to the coax for power conversion and DOCSIS backhaul. Each gateway requires 20W
- The coax is a common 0.625in diameter cable with resistance of 0.0011 ohms/ft
- The gateway / small cell minimum input voltage is 45V
- The operator's powering policy states that any broadband UPS can be loaded to maximum 85% of rated capacity.

With these parameters we calculate the power example as follows:

$$P(\text{Actives}) = P(\text{node}) + 4 \times (P(\text{small cell}) + P(\text{gateway}))$$

$$\text{Total Power (Actives)} = 190W + 4 \times (100W + 20W) = 670W$$

Adding coax line loss or I^2R loss adds an additional 13W. The results are summarized:

Table 7 – 5G Fixed Access Wireless Powering Results

Configuration	PS I(out)	EOL Voltage	Actives Load	I^2R Loss	PS Utilization
DAA node, 4x 5G small cell radios each with HFC interface gateways	7.6A	86.7V	670W	13.4W	51%

3.2.5. EPON

Ethernet passive optical network (EPON) has supported 10Gbps symmetrical data for years. Recently, the Institute of Electrical and Electronics Engineers (IEEE) has approved a 25G/50G-EPON standard. When viewed through the lens of the 10G initiative, cable broadband customers with EPON service are in good shape. Figure 11 represents an EPON network block diagram.

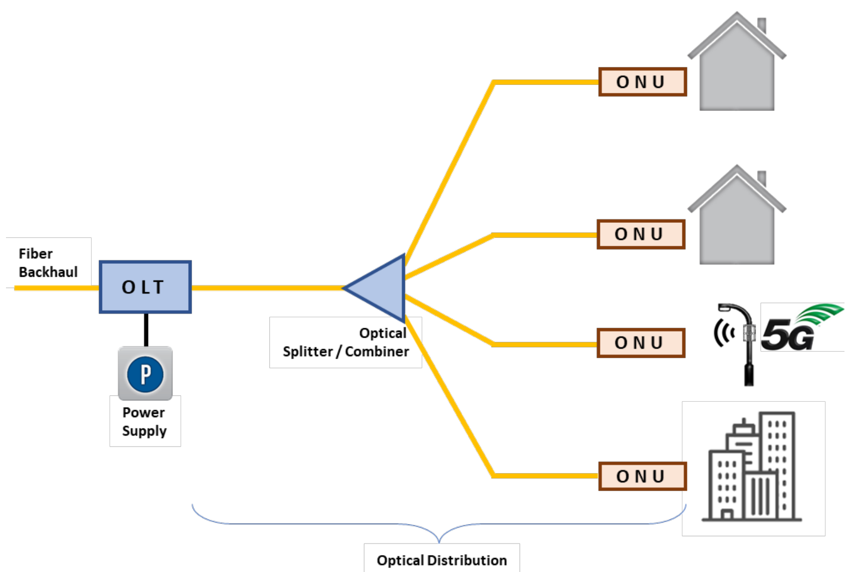

Figure 11 – EPON Block Diagram

Powering an EPON network segment is straightforward and familiar to most operators. EPON is an all-fiber network which consists of only passive optical components (splitters and combiners), except at the endpoints of each fiber, where there is an electrically-powered termination device – either an optical line terminal (OLT) or optical network unit (ONU). EPON is a point-to-multipoint topology in which downstream transmission from an OLT is received by all ONUs, but upstream transmission by an ONU is received only by the OLT. The OLT is often powered from a broadband UPS. That UPS may be dedicated to the OLT or may also power optical nodes and amplifiers in adjacent network segments. The ONU is powered from the premises (home or business) except for cases where the ONU services part of the access network infrastructure. An example is shown in our EPON block diagram where one ONU is providing a backhaul connection to a 5G small cell radio. In such cases, the ONU and 5G small cell radio are typically powered from a nearby coax segment as described in a previous example.

4. Ensuring Reliable Power

4.1. Power Reliability Considerations

In 2019 a North American operator was experiencing problems with their digital nodes. Some of their R-PHY nodes were resetting. After a reset these nodes required several minutes to power-up and provision. The result was loss of service for several hundred customers within the service areas of the effected nodes. After extensive investigation by the operator and by multiple vendors the root cause for the resetting nodes was determined to be power related. Technicians working downline from the node were servicing network components and had inadvertently shorted the coax center conductor to ground causing a brief power disruption. The power anomaly was sufficient enough to cause the node to reset, dropping customer service for several minutes.

This example illustrates the critical nature of reliable power. Power reliability is especially vital with digital nodes where power disruptions can cause CPUs to reset. The node must reboot and then re-establish communications links independently to both the headend and to each user. The re-boot and re-provisioning cycle have been observed to take up to 15 minutes with some DAA devices. Many power related service disruptions can be mitigated with planning and preparation. A few ideas are discussed here.

4.1.1. Intra-Node Power Hold-Up Time

In the prior node reset example the cause of the power disruption was a momentary short of the coax cable carrying power to the node. A UPS system that is operating perfectly could not mitigate this type of power disruption. To the UPS system a coax line short would appear as a current spike on its output. If the short occurred close enough to the UPS, its ferro-resonant transformer would fold-back, dropping output voltage until the fault was cleared. If the line short was some distance from the UPS, the coax line resistance would mitigate the short and it would appear to the UPS output as a temporary rise in current.

The UPS has no way of protecting the node power input from this type of line fault. Avoiding power glitch related node resets requires keeping the node's internal logic power bus from dropping. Node vendors are experimenting with internal capacitors and batteries to this end. Capacitors should prove effective for short power disruptions of no more than a few 60Hz AC cycles (60-70ms). Extended hold-up times my require an internal battery or second power input to the node. Neither option is desirable. Internal batteries would require eventual replacement and a redundant second power input is complex and expensive.

4.1.2. Utility Backup Time

Increased power consumption from equipment such as future DAA nodes requires a review of UPS runtime capacity. With new architectures and equipment, what is the net effect on power consumption? Do the UPS systems still meet minimum runtime requirements? Operators must evaluate their networks by the criticality of each location. New DAA nodes may service business customers requiring longer utility backup than residential customers.

One utility power backup exception that California based operators must address is described in State Senate bill No. 431 introduced in June 2019. This bill requires some telecommunications equipment in high fire threat areas to support 72 hours of communications during utility outages. If this legislation is applied to cable operators, extensive upgrades to their power backup systems will be required. For the access network, this would likely take the form of natural gas or propane generators at each broadband UPS installation. However, is it wise or even practical to have natural gas, propane or other combustible fuel source in zones declared high risk fire zones?

4.1.3. Redundant Power Source

Network equipment such as VHubs and DAA nodes often support large service areas or critical business customers. Do these devices have adequate power backup? In some installations operators have utilized a second (redundant) power pack within the node or VHub to insert power from a second UPS to create a fully redundant power backup for these critical devices. This redundant power may come from a second dedicated UPS system but would likely be diverted from a nearby coax segment powered from a different UPS than is powering the critical node or VHub.

4.2. Backup Power Requires Healthy Batteries

The ability of broadband UPS systems to provide uninterrupted power is directly related to the condition of the UPS system batteries. Aspects of battery health and maintenance relating to outside plant (OSP) UPS operation are discussed here.

Multiple factors impact battery runtime and health. For clarity, runtime as used here is defined as the instantaneous stored energy available from a battery or bank of batteries irrespective of environment or history. Battery health is defined as the present maximum capacity of a battery or bank of batteries. Five primary factors affect battery runtime and battery state of health. These are: state of charge, ambient temperature, temperature history, battery age and charge history. Sections in 4.2 discusses charge history and its effect on both battery runtime and battery health or capacity. Note that this discussion applies to lead-acid types of batteries, which are commonly deployed in HFC networks due to their lower cost. As new battery technologies become available and cost effectively deployed, the conclusions below will need to be modified based on the characteristics of the newer battery technologies.

4.2.1. Effects of Charge on Battery Capacity

Overcharging and undercharging batteries has a significant effect on battery life. Using charging specifications from battery manufacturers, the following discussion illustrates how overcharging or undercharging batteries can cause premature battery failure.

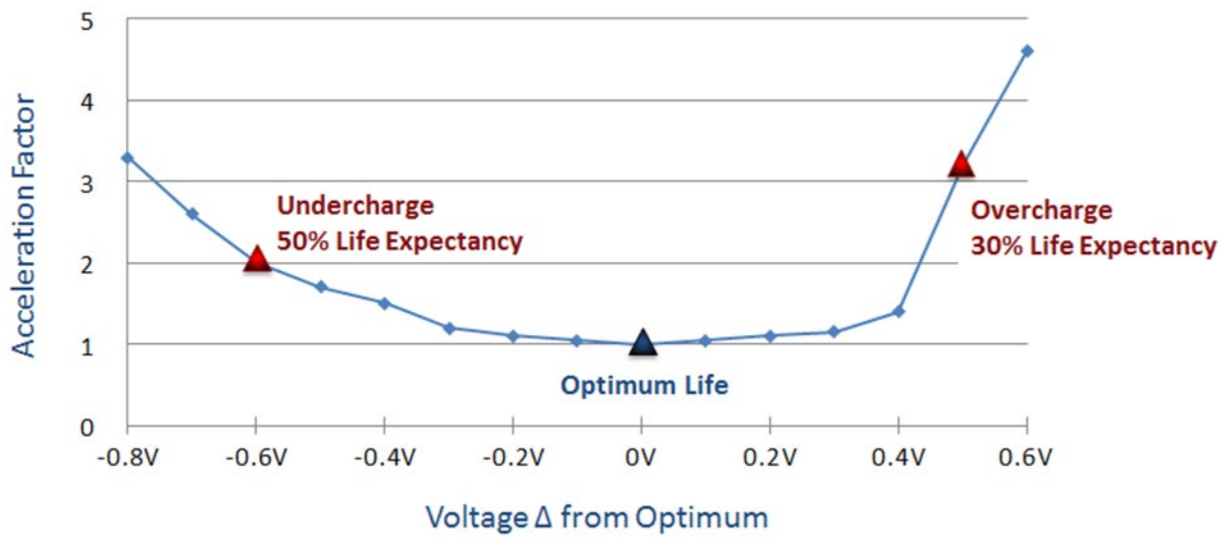

Figure 12 – Charge Effect on Battery Life

In this diagram, the X-axis identifies specific voltages under and over the optimum charging voltage. The Y-axis shows the acceleration factor or multiplier on battery life. For example, if a battery were undercharged by 0.6V, its effective age would accelerate by a factor of 2x resulting in a reduction of useful life to 50% of that battery's optimum life. Likewise, if a battery were overcharged by 0.5V, its useful life would be only 30% of its optimum life.

Any charge related degradation effect occurs only while the overcharge or undercharge condition is applied. For example, undercharging a battery by 0.6V for a period of 4 months (perhaps the duration until the next preventative maintenance cycle) would result in a loss of 2 months to the overall life of the battery (using a 2x acceleration factor for 0.6V undercharge.) Once the charge problem is corrected, no further damage will occur, however, the capacity has nonetheless been permanently diminished.

4.2.2. Battery Chemistry and Charge Mismatch

Typical OSP power supply installations include one or multiple battery strings. Each battery string consists of 12V batteries connected in series. Three series batteries are combined to achieve a 36V string or four batteries are configured for a 48V string. The connection between the power supply and the battery string(s) is through a wire harness connected across the entire string (i.e., one connection is at the negative terminal of the first battery (ground), the second connection at the positive terminal of the third battery for 36V strings or the fourth battery for 48V strings). In this configuration, power from the batteries and charge to the batteries is routed through the wire harness for the entire string. A three battery, 36V battery string is shown in Figure 13.

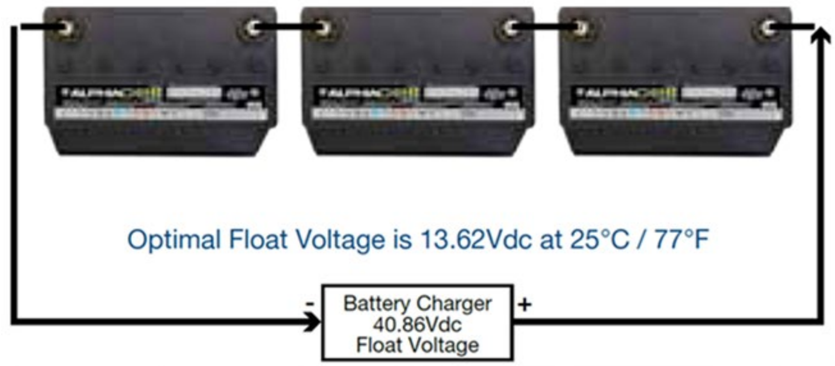

Figure 13 – Battery Charge Configuration

Optimal float voltage is also listed for this 36V string as 13.62Vdc per battery. This value may vary among different battery manufacturers and technologies. The broadband UPS is configured to supply 40.86Vdc across the entire battery string. From the charger's perspective, each battery appears in the circuit as a fixed resistance. Per Ohm's law, the three batteries, acting as resistors in series, create a voltage divider and the 40.86Vdc is distributed equally across each of the batteries at 13.62Vdc per battery.

Batteries operate via electro-chemical reactions. Time, temperature and charge history can affect this chemistry, thus altering the battery's internal resistance. If each battery in in a battery string has internal resistance values that change at different rates, the 40.86Vdc charge voltage will not be applied equally across each battery. The result of this unequal internal battery resistance is illustrated here.

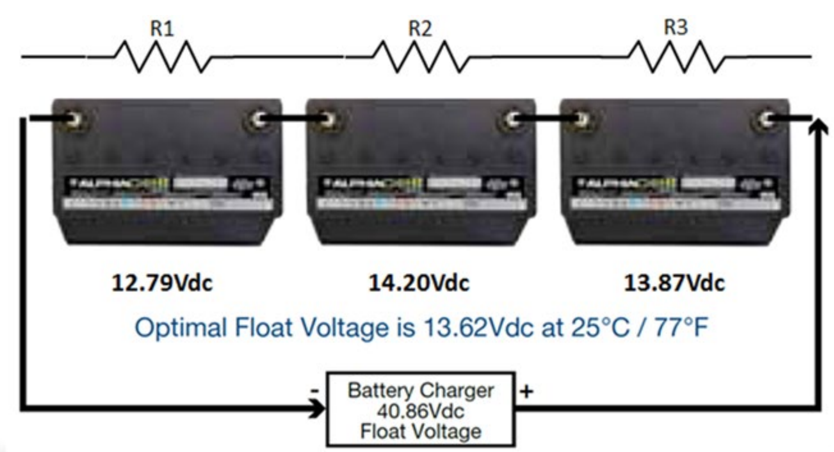

Figure 14 – Internal Battery Resistance

As the internal resistance of each battery changes at different rates over time, the effective circuit where R1≠R2≠R3 causes the charge voltage to be distributed unequally across the three batteries. The result is that some batteries will be undercharged while others are overcharged. In our example one battery is undercharged at 12.79Vdc while the other two batteries are overcharged at 14.20Vdc and 13.78Vdc. The total charge voltage of 40.86Vdc is correct, but the battery chemistry has caused an internal string charge variation that will shorten the life of all three batteries over time if not corrected.

OSP monitoring software can be configured to identify disparate voltages within individual battery strings for maintenance before extended battery damage occurs. Operators should consult battery manufacturers for specific voltage threshold parameters to trigger alerts and initiate corrective action. Multiple options exist to mitigate the effects of time on internal battery resistance. Some modern UPS systems are equipped with charge balancing technology that will automatically re-direct charge within a battery string to offset the effect of changes to internal battery resistance. This charge management technology is available from various manufacturers in a variety of configurations. Operators should be aware of the effects of charge imbalance on battery life and determine the best course of action for their situation.

4.2.3. Preventative Maintenance is Essential

In 2016, a major North American operator conducted an investigation to determine the root cause of their growing number of OSP broadband UPS alarms. Standby test fail alarms were of particular interest due to the critical nature of this alarm. Across three (3) cities, this operator identified that 22% of their broadband UPS systems had failed standby tests, due in part, to battery cable corrosion. The following shows representative battery corrosion at one of these installations.

Figure 15 – Battery Corrosion

The center battery shows excessive corrosion around both the positive and negative battery posts. This type and level of corrosion can occur with some styles of OSP batteries that have not been properly maintained. At the conclusion of their investigation, the operator identified deficiencies in their local OSP preventative maintenance (PM) practices that led to these potentially service-impacting results.

Corrosion will damage battery power cables and battery voltage monitoring sense wires. As battery power cables degrade, electrical resistance increases and the ability of the batteries to provide sufficient current diminishes. Eventually, as this operator experienced, the corrosion will increase cable resistance sufficiently to cause a broadband UPS standby test to fail. Prior to a standby test failure, backup capacity had diminished and the expected runtimes during actual power outages were lower. Had an actual utility outage occurred, standby power would be compromised and customer loads dropped, potentially before the standby test indicated any problem.

Could this liability have been avoided through more diligent preventative maintenance practices? The answer, of course, is yes. "How frequently should each UPS be visited?" is an often debated question. Responses vary between operators and even between systems within the same operator. These answers range from six-months to two-years when technicians are queried. Conducting PM visits and finding nothing to correct is wasting valuable service resources. Waiting too long between PM visits could result in service impacting situations going unchecked. One often hears reports of PM visits to multiple installations within a geographic area with some locations checking out OK while other sites require extensive maintenance. Clearly, there is no one right answer to the question of PM frequency. Can anything be done to reduce unneeded PM visits while focusing limited resource on locations needing physical intervention?

The answer to this question is two-fold:

- First, there are some issues that require on-site inspection to identify and correct. Examples include pest infestations and water intrusion due to physical enclosure damage. Because this category of problems exists, scheduled preventative maintenance visits are required.
- Second, it may be possible to identify a category of future service-affecting problems through analysis of data available from status monitoring systems. This would enable operators to prioritize site visits around locations at high risk of causing future service disruptions. Low risk sites could be visited less frequently and only to inspect and correct issues that are undetectable any other way.

5. Conclusion

This white paper discussed access network powering considerations related to network upgrades intended to support new services that will reach and eventually surpass performance goals of the 10G initiative.

A traditional HFC network powering approach was used as a baseline for other powering examples. Upgrading to a DAA network topology was reviewed and a near future DAA node defined and used in several powering scenarios. Between the DAA node and the premises, powering for multiple network architectures was discussed including last-mile access via a deep fiber N+0 approach and a 5G fixed wireless access approach.

Several powering themes became apparent as different access network scenarios were reviewed.

1. Experience with powering of traditional HFC networks is foundational. An understanding of both active loads and I^2R losses is a good starting point for analyzing power demand of network upgrades. Coax line losses play a major factor in powering decisions, especially as new active devices are placed some distance from the UPS.
2. Digital line gear including DAA nodes require more power than their analog counterparts and they are more sensitive to power disruptions. A DAA node (or VHub) reset has the potential to drop many customers for several minutes as processors reset and communications are re-provisioned. Policies regarding power quality, redundancy and backup time should be established before any significant DAA system upgrades.
3. Since access network equipment presents a constant power load to the network, I^2C line loss and EOL voltage are interrelated. Higher line loss (due to coax length as well as other factors) results in more current draw through the coax which results in lower EOL voltage.

This paper also discussed ways to ensure power reliability with an emphasis on batteries. Battery charge management is essential to battery life and ultimately to maintaining network uptime during power utility disruptions. Internal battery chemistry changes over time will result in the battery internal resistance changing at different rates, requiring active monitoring and management to ensure that batteries are charged correctly over their entire service life. Finally, on-site maintenance is needed to oversee aspects of the UPS system that cannot be managed remotely, such as damage and corrosion from weather and fauna.

This paper reviewed only a few representative network powering scenarios. Powering designs for live networks must be engineered alongside the network architecture being powered to ensure that power quality and quantity is sufficient for the near future network requirements.

Abbreviations

10G	10 gigabit
5G	fifth generation technology standards for cellular networks
AP	access point
ASIC	application specific integrated circuit
bps	bits per second
CBRS	citizens broadband radio service
CCAP	converged cable access platform
CPU	central processing unit
DAA	distributed access architecture
DCA	distributed CCAP architecture
DOCSIS	data over cable service interface specification
EPON	Ethernet passive optical network
ESD	extended spectrum DOCSIS
FDD	full duplex DOCSIS
FEC	forward error correction
FPGA	field programmable gate array
FWA	fixed wireless access
GAP	generic access platform
HD	high definition
HFC	hybrid fiber-coax
Hz	hertz
IoT	internet of things
ISBE	International Society of Broadband Experts
MAC	media access control
N+0	node plus zero amplifiers
ODC	optical distribution center
OLT	optical line terminal
ONT	optical network terminal
OSP	outside plant
OTT	over the top
PIM	protective interface module
PNM	proactive network maintenance
PON	passive optical network
RAN	radio area network
RF	radio frequency
R-MACPHY	remote mac and physical layers
R-PHY	remote physical layer
SCTE	Society of Cable Telecommunications Engineers
vCCAP	virtual CCAP
vCMTS	virtual cable modem termination system
Wi-Fi 6	sixth generation wireless intent standards, also known as 802.11ax

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